**Multicomponent Seismic Data Acquisition and Imaging**
SEG/SPG 2011 Shenzhen Conference - Workshop
November 7, 2011, 2:00pm - 5:30pm
Presented by Prof. Bob Hardage and Dr. Lee Bell
Registration Fee: US$50

**Bob Hardage** is Senior Research Scientist at the Bureau of Economic Geology and chief scientist of the Exploration Geophysics Laboratory (EGL). EGL focuses on the development and application of multicomponent seismic technology. Before moving to the Bureau in 1991, Bob was Exploration Manager for Asia/South America at Phillips Petroleum Company and Vice President of Marketing and Geophysical Development at Western Atlas. He has written four books on seismic topics, published numerous papers in technical journals, and teaches short courses and workshops on various seismic topics at several venues each year. He is past Editor of *GEOPHYSICS*, writes the monthly *Geophysical Corner* article for the AAPG Explorer magazine, and has served on four SEG Executive Committees. He is currently President of SEG.

**Lee Bell** received his PhD (1977) in geophysics from Stanford University. He joined Mobil R&D in Dallas as a research geophysicist and then Digicon as managing director of the Aramco Research Group (1981). Bell started the data processing company Entropic Geophysical in 1984 and merged it with Geosignal in 1991, where he served as vice president and then president. After Geosignal was acquired in 1997, Bell became vice president of technology for Western Geophysical. After the formation of WesternGeco, he managed its Reservoir Services Division. In 2004, Bell accepted the position of president of Geophysical Development Corporation and in 2007 became the chief geophysicist of the parent company, Geokinetics. Bell has been a member of SEG since 1972. He has authored and coauthored numerous presentations for the annual and regional meetings in the fields of signal processing and inversion. He is serving as an SEG district representative, and was the treasurer of the Board of Directors of SEG Global, Inc., and also serves on the EAGE-SEG Collaboration Committee. He is a member of EAGE and the Geophysical Society of Houston.

## Lecture 1: Direct Shear Waves from Vertical-Force Sources

**Presented by Bob A. Hardage**

Vertical-force sources can be segregated into three general classes of sources – vertical vibrators, vertical impacts, and shot-hole explosives. For decades geophysicists have viewed vertical-force sources as only P-wave sources. Any shear (S) wave information produced by such sources has been limited to converted-SV (P-SV) modes produced by downgoing P waves at interfaces remote from a source station.

For several years, researchers at the Exploration Geophysics Laboratory have investigated the physics of wave modes produced by vertical-force sources. Our conclusion is that a full-elastic wavefield, consisting of P, SV, and SH wave modes, is produced directly at the point where a vertical-force source applies its force vector to the Earth. The SV and SH shear-wave modes produced in this manner are called **direct-S** modes to distinguish them from converted-S modes produced by a vertical-force source

The basic physics of P, SV, and SH mode generation by a vertical-force source will be discussed, and data examples generated by vertical vibrators, vertical impacts, and shot-hole explosives will be shown to verify the presence of these modes in all classes of vertical-force data. This paper will emphasize the economic impact of this new method for acquiring S-wave data.

The methodology by which direct-S modes are generated and extracted from vertical-force-source data has been patented, with worldwide coverage, by the Board of Regents of The University of Texas System.

## Lecture 2: P-Wave and S-Wave Backscatter Noise across Surface Exposed High-Velocity Rocks

**Presented by Bob A. Hardage**

Seismic data acquired across areas where high-velocity rocks (metamorphics, igeneous, carbonates) are exposed at the Earth surface tend to be poor quality. There are published studies showing SH-shear data are better quality than conventional P-P (compressional-wave) data across surfaces of exposed high-velocity rocks. Distinctions between SH-mode and P-mode wave physics across hard-rock geological surface are striking and need further study and research. Some of the basic wave physics that applies when P and SH surface waves propagate across exposed high-velocity rocks will be presented in this discussion.

The Exploration Geophysics Laboratory conducted a field test to study the basic physics of SH and P wave propagation across an area where the Earth surface changes from unconsolidated material to hard, high-velocity rocks. These test data show dramatic differences between the propagation of Love waves (SH surface waves) and Rayleigh waves (P surface waves). Definitive data examples will be shown and discussed to illustrate that Love waves and Rayleigh waves propagate as wave physics predicts, and that these surface waves backscatter from surface and near-surface anomalies in different ways, depending on whether the surface is unconsolidated or hard. The number and magnitudes of these backscattered surface waves control the signal-to-noise ratio of SH and P data and limit a data processor's success in extracting SH and P reflection events across areas of exposed high-velocity rocks.

These test data were acquired to assist the exploitation of geothermal energy; however, Earth surfaces with similar geology exist above many hydrocarbon prospects.

## Lecture 3: Analysis of a 3D-3C Dataset for Fracture Related Anisotropy over the Marcellus Shale

**Presented by Lee Bell**

The utilization of seismic data to identify and characterize gas shales and their fractures is an important contributor to economically producing them. Geokinetics has recently acquired high-density, wide-azimuth 3D single-component data over large area of the Marcellus Shale in Bradford County in northeastern Pennsylvania. As part of that acquisition a 25 sq mi multicomponent test was recorded as a test to determine what additional information may be determined with this technology. Utilizing these data, both the P-waves and PS converted waves were analyzed for anisotropy which could be related to localized fracturing within the Marcellus Shale and the surrounding geology.

In the case of the P-wave data, pre-stack time migration of offset vector tiles was used to preserve offset and azimuthal information. These data were used to determine the elliptical velocities to get the azimuth of the ellipse and the maximum and minimum velocities.

For the PS data, the primary analysis was the amount of shear wave splitting that could be observed. Shear wave splitting was based on the rotation of the horizontal components to correspond to the maximum and minimum stress directions. This required imaging two separate sections, S1 and S2, and registering the two for differential time shifts. The sample by sample time differential gives an indication of local fracture intensity. In addition the PS image is registered to the PP image to give a common reference for comparisons.

The methodology used to obtain a measure of the horizontal anisotropy is briefly described for each dataset. The observed results for both the P-wave and PS-wave are compared and correlated with respect to each other.

## Lecture 4: Four Component OBC Processing Challenges

**Presented by Lee Bell**

The shallow water offshore shelf of northwestern Australia poses unique challenges for seismic imaging. A hard water bottom with a very shallow high velocity carbonate typlifies the first 700 m of section. Below this are approximately 500 m of lower velocity clastics, mostly sandstones, which sit on top of another carbonate shelf. Below the second cabonate section is a mostly shale section. The targets are sand deposits at 4200 m depth or approximately 2.3 seconds two-way time. The combination of fast, slow and fast rocks not only make energy penetration difficult but sets up strong reverberations and multiples.

Imaging with streamer data in this region is difficult because of the narrow azimuth acquisition and the strong multiple content. Multicomponent OBC provides an edge in that the wide azimuth geometry helps to suppress the multiples and the summation of the hydrophone and geophone reduces the reverberations. Unfortunately, a drawback to OBC is that economic restrictions impose a larger receiver spacing than could be achieved by typical streamer

geometries. The coarser grid has implications throughout the processing sequence in order to avoid aliasing either signal or noise.

In this case study, 225 square km of OBC were acquired and processed. The 4 component Sercel Searay was used for the data acquisition. Processing for a P-wave section included:

- Designature for hydrophone and accelerometer
- Hydrophone and accelerometer summation
- Multi-azimuth noise removal in receiver and shot domains
- Deconvolution
- Detailed velocity analysis with well control
- Moveout based linear noise removal
- Kirchhoff PSTM
- Residual velocity analysis.
- Radon based de-multiple
- Post-stack signal enhancement.

We describe the acquisition and processing of these data to the final prestack time migration image. In particular we focus on the pre-imaging processing to remove source generated noise, reverberations and multiples.